22 November 1967

Materiel Test Procedure 7-2-070
General Equipment Test Activity

U. S. ARMY TEST AND EVALUATION COMMAND
COMMODITY ENGINEERING TEST PROCEDURE

MAT SETS, LANDING

1. OBJECTIVE

This document provides test methods and techniques used to determine the technical performance and safety characteristics of landing mat sets and their associated tools and equipment as described in Qualitative Materiel Requirements (QMR's), Small Development Requirements (SDR's), Technical Characteristics (TC's) and their design criteria.

2. BACKGROUND

The Armed Forces have a continuing need for a portable, lightweight, landing mat for use in forward areas as airfield surfacing. The need for (prefabricated) airfield surfacing materiel was established in the early days of World War II. Modern concepts of mobility in combined arms warfare have served to intensify the demand for lightweight, rapidly constructed airplane landing mats.

3. REQUIRED EQUIPMENT

a. Rough-terrain forklift
b. Aircraft arresting gear
c. Aircraft catapult assembly components
d. Heavy duty air compressor
e. Jack hammer
f. Sledge hammers
g. Aircraft
h. Aircraft air and ground crews
i. Rakes and shovels
j. Adjustable wrenches
k. Crowbars
l. Four-by-four (or larger) wood blocking
m. Brooms
n. Cutting and welding equipment
o. Micrometer
p. Airfield penetrometer - a portable, hand-operated instrument to measure soil strength in relatively low-strength soils
q. Airfield surface profilometer
r. Cone penetrometer
s. Dynamometer
t. Load cart, pneumatic-tired
u. Universal analyzer
v. Direct-inking oscillograph
w. High speed camera with recticle lens
x. Paper type gauge targets

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4. REFERENCES

A. USAMC Regulation 385-12 Verification of Safety of Materiel from Development through Testing and Supply Disposition.
B. USATECOM Regulation 385-6 Safety Release.
C. USATECOM Regulation 705-4 Equipment Performance Report.
D. AR 705-15 Operation of Materiel Under Extreme Conditions of Environment, with Change 1, 14 October 1963.
E. ASTM Std-C481-62 Method of Test for Laboratory Aging of Sandwich Constructions.
F. TM 5-530 Materials Testing
G. TM 5-366 Planning and Design for Rapid Airfield
H. USATECOM Regulation 700-1 Value Analyses
I. MTP 10-2-500 Physical Characteristics.
J. MTP 10-2-501 Operator Training and Familiarization
K. MTP 7-2-506 Ground Transportability of CBR equipment
L. MTP 10-2-507 Maintenance Evaluation
M. MTP 10-2-505 Human Factors
N. MTP 10-4-001 Desert Environmental Test of General Supplies and Equipment
O. MTP 10-4-002 Arctic Environmental Test of General Supplies and Equipment
P. MTP 10-4-003 Tropic Environmental Test of General Supplies and Equipment
Q. MTP 10-2-502 Durability

5. SCOPE

5.1 SUMMARY

This Materiel Test Procedure contains the following procedures for the testing of Landing Mat Sets:

a. Arrival Inspections - An evaluation of the physical characteristics of the material in which the test item was packed and a determination of any damage to the test item due to manufacturing, packaging, shipping, etc.

b. Safety Test-An evaluation of the test item for any possible toxic hazards

c. Laboratory Tests consisting of:

1) Physical characteristics
2) Durability
3) Skid Resistance and Tire Wear

d. Field Tests consisting of:

1) Topographical Data - a procedure to ensure the test site meets engineering criteria and specifications
2) Soil strength - a procedure to determine if the California Bearing Ratio (CBR) meets military specifications
3) Installation
4) Trafficability and Wheel Load Test - a procedure to determine

the ability of the test item to withstand specified air traffic

5) Mat Deflection, Behavior, and Bow Wave Test

e. Maintenance Evaluation

f. Human Factors - a determination of the ability of personnel to work with the test item.

g. Safety Evaluation

h. Environmental Testing

i. Value Analysis

6. PROCEDURES

6.1 PREPARATION FOR TEST

6.1.1 Operator Training and Familiarization

Ensure the presence of test personnel capable of meeting the criteria of MTP 10-2-501 and the following:

a. Assembling the test item
b. Installing the test item
c. Operating the test item
d. Maintaining the test item

6.1.2 Arrival Inspections

Upon receipt of the test item, subject it (and a standard of comparison, if applicable) to the following procedures:

a. Visually inspect the material in which the test item arrived and record the following:

1) Evidence of package deterioration or damage that may have occurred during storage or transit
2) Identification markings, including:

a) Name of contractor
b) Number and date of the contract
c) Date of manufacture
d) Other markings pertaining to the test item

3) Weight
4) Physical dimensions (length, width, height)
5) Type of material

b. Photograph the test item(s) to identify the crates and their condition.

c. Uncrate the test items, as directed in the test item's maintenance package, and record the following:

1) Ease of uncrating
2) Method of packing
3) Equipment required for unpacking
4) Adequacy of uncrating instructions

d. Visually inspect the test item and record the following, when applicable:

NOTE: Make use of photographs, narratives and diagrams to indicate the condition of the test item and its accessories.

1) Evidence of damage or deterioration
2) Evidence of incompleteness
3) Evidence of wear
4) Evidence of defects

a) Manufacturing
b) Material
c) Workmanship

e. Examine the mat bundles to ensure that they had been secured in accordance with the appropriate Federal Specification and record any deviations.

6.1.3 Safety

a. Obtain the developer's safety statement summarizing pertinent safety findings during testing and specifying any safety precautions that should be observed during emplacement or use of the test item.

b. Determine if the test item, its associated tools and equipment are nontoxic and nonhazardous to personnel when used in accordance with instructions from the developer.

c. If applicable, submit to the Office of the Surgeon General a request for toxicity clearance for testing.

NOTE: Furnish OSG copies of the test plan with complete description, chemical composition, and manufacturer of all nonstandard liquids or solutions to be used with the test item.

6.2 TEST CONDUCT

a. Test operations shall be continued regardless of adverse weather conditions except when such conditions would compromise test results or endanger life or property.

NOTE: If a correction in a test operation or technique, after field analysis, is warranted, the new procedure and the difficulty prompting the change will be noted.

b. Throughout testing, photographs and motion pictures will be taken as appropriate to illustrate test results and equipment faults.

6.2.1 Laboratory Tests

Perform and/or confirm laboratory determinations of the following physical properties of the test item and accessories making a minimum of three observations in each test area.

6.2.1.1 Physical Characteristics

Subject the test item (and a standard of comparison, if applicable) to the applicable sections of MTP 10-2-500 and the following procedures:

a. Determine and record the following:

1) Cubage of each bundle of mats
2) Weight
3) Placing and overall dimensions of each bundle
4) Functional performance, when applicable of

a) Latches
b) Hinges
c) Closures, etc.

b. Visually inspect all panels from 2 to 4 bundles from each delivery of 100 bundles, for the following, as applicables and record data regarding essential characteristics expressed in the appropriate QMR's, SDR's, and MC's:

1) Alloy
2) Tolerances in side joints, etc.
3) Weight
4) Fit
5) Adhesion of anti-skid additive to the mat surface
6) Any panels that dish transversely
7) Appropriate coding according to statistical design number, capacity, serial number, lifting points, etc.
8) Existance of shortages

NOTE: Render an Equipment Performance Report (EPR) on any deficiencies/defects noted.

c. Measure one panel, from each opened bundle, with a micrometer. Record and compare the measurements to specified dimensions.

d. Visually inspect the following accessories, as applicable, for specified requirements:

1) Replacement mats
2) Aircraft tiedowns
3) Ninety degree connectors
4) Starter keylock
5) Typical keylock
6) Arresting gear

7) Transition mat section
8) Anchorage items
9) Expandable panels
10) Starter and access adapters

6.2.1.2 Durability

a. Collect and record data as described in the applicable portions of MTP 10-2-502 including the following:

1) Tensile test
2) Beam test - flexure, shear and compression determinations
3) Aging test
4) Extreme temperature test

b. Observe and record the following:

1) Durability of the anti-skid coating
2) Waterproofing capabilities before and after tests
3) Resistance to adverse weather conditions, aircraft engine exhaust, and fuels

c. Measure and record the percentage of expansion/elongation during temperature changes as specified.

6.2.1.3 Skid-Resistance and Tire-Wear Tests

a. Install a section of the test item in the laboratory
b. Inflate the tires of a load cart to the required psi

NOTE: The weight of the load cart is sufficient to achieve the specified poundage on each wheel.

c. Attach a dynamometer between the load cart and the motor patrol.
d. Lock the wheels of the cart
e. Pull the cart over the mat section at a uniform speed
f. Rotate the tires slightly, to expose a new surface, and pull the cart back across mat
g. Record the following for each direction of pull:

1) Direction of pull
2) Length of pull
3) Tire pressure
4) Load weight
5) Average Force required to keep cart moving
6) Comparative tire wear by means of visual observations and photographs

6.2.1.4 Trafficability and Wheel Load Tests

a. Prepare the load cart with the proper single-wheel load weight

and tire pressure for the specific test item as described in the test plan.

b. Drive or pull the load cart forward along the test sections and then backward as nearly as possible along the same track.

c. Shift the cart laterally, by one tire width and repeat step b above.

d. Repeat steps b and c above until the entire traffic lane has been covered and record the following:

1) Single-wheel load weight and tire pressure
2) Tire contact area
3) Wheel coverage
4) Soil CBR
5) Test item: Ability to withstand single-wheel loads and tire pressure without significant deformation or damage.

NOTE: Mat should be capable of removal or reuse with rehabilitation.

6) Condition and performance of waterproof properties

e. All mat accessories listed in paragraph 6.1.2.1.g, as applicable, shall meet the above requirements in addition to the following:

1) Functional suitability
2) Tolerances
3) Weight
4) Fit
5) Aircraft tiedown strength test

f. List any failed materiel

1) Identity
2) Description of failure
3) Location of item at failure
4) CBR of soil under failed item at failure
5) Number of load coverages sustained by failed item.

g. Survey and record data of centerline profile and cross sections of the runway and taxiway surface elevations and compare to the pretest data to determine any permanent deformations of the overall matted surface.

h. Measure and record deflection and/or mat creep by measuring the distances from reference points on the matting to fixed references outside the matting surface. Record:

1) Magnitude of mat creep
2) Location of mat creep
3) Resulting buckling, if applicable

i. Photograph all failed or deformed test specimens, mats, and mat packages

6.2.2 Field Tests

6.2.2.1 Pre-Test Preparation

6.2.2.1.1 Topographical Data - Perform the following:

Obtain the necessary topographical and survey data, including maps to assure conformance of the test site with specified construction criteria.

6.2.2.1.2 Soil Strength Test - Perform the following:

a. Determine and record the California Bearing Ratio (CBR) as described in Appendix A and/or Reference 4F of the soil by means of both the portable cone penetrometer and truck mounted gauges taking samples of the entire test area at a maximum of 50 feet apart.

b. Classify and record each soil sample taken according to the following:

1) Sample location
2) Water content
3) Density
4) CBR

NOTE 1: In no case shall the subgrade CBR be less than prescribed.

2: Cone penetrometer reading and moisture determinations shall be made on uncovered soil adjacent to the mat and on soil under the test item a minimum of twice a week for the duration of the test.

3: During the test, the CBR of the soil under the test area will be maintained at the prescribed level. This may be accomplished by adding water to the soil to replace moisture lost by evaporation.

c. Determine, through qualitative observations, the dust proofing capability inherent in the mats and of the various dust palliatives applied to shoulders and overruns of the airfield.

6.2.2.1.3 Installation and Measurements - Perform the following:

a. Assemble and install the test item on the prepared test site according to appropriate specifications and procedures.

b. Record the following:

1) Time and number of personnel to install
2) Effort and difficulties encountered
3) Special tools or supplies needed that were not supplied with the test item kit

4) Adequacy of accompanying directions and specifications
5) Fit and interchangeability of parts

c. Survey the center line profile and cross sections of the runway and taxiway surface elevations and record the data

d. Establish, mark, and record fixed reference points, at every 100 feet of runway, for determination of deflection and mat creep.

6.2.2.2 Aircraft Operations

a. Establish and record data as prescribed in paragraph 6.2.2.1.3 steps c and d.

b. Position a minimum of 10 paper type gauge targets across the runway in a staggered fashion and photograph evidence of bow wave during aircraft operations with a high speed camera equipped with a reticle lens.

c. Conduct the specified aircraft operations which include:

1) Maximum takeoffs using after burners
2) Arrested landing with tail hook
3) Assault landings utilizing maximum wheel braking

d. Determine and record the maximum surface roughness that can be tolerated by specified aircraft using an instrumented aircraft and an airfield surface profilometer. Record the following:

1) Aircraft shock and vibration data
2) Profilometer readings
3) Daily flight operation data
4) Conditions of test material
5) Pilot reactions
6) Effects of surface roughness on aircraft, structurally

NOTE: This data shall be correlated with other test data concerning flight operations and conditions of test material.

e. Record data as prescribed by paragraph 6.2.1.4, steps g, h, and i.

6.2.3 Maintenance Evaluation

Collect and record data as described in the applicable sections of MTP 10-2-507.

6.2.4 Human Factors

Collect and record data as described in the applicable sections of MTP 10-2-505.

6.2.5 Safety Evaluation

a. Determine and record the following during the conduct of the test:

1) Conditions that might present safety hazards
2) Cause of safety hazards
3) Action taken to alleviate hazards
4) Special precautions required for operating and maintaining the test item

b. A safety release recommendation shall be issued in accordance with USATECOM Regulation 385-6

6.2.6 Environmental Testing

Testing under conditions of arctic, desert, and tropic conditions shall be performed as described in MTP 10-4-001, MTP 10-4-002, and MTP 10-4-003.

6.2.7 Value Analysis

a. During operation and maintenance of the test item, determine and record whether the test item incorporates any features that could be eliminated without compromising their performance, reliability, durability, or safety. (See Reference 4G)

b. Personnel testing the item shall be questioned regarding any features of the mat that may be eliminated without decreasing the functional value and their comments recorded.

c. Comparison of cost shall be made between test items and existing items.

6.3 TEST DATA

6.3.1 Preparation for Test

6.3.1.1 Operator Training and Familarization

Record data collected as described in MTP 10-2-501

6.3.1.2 Arrival Inspection

a. Record the following:

1) Evidence of package deterioration or damage that may have occurred during storage or transit.
2) Identification markings, including:

a) Name of contractor
b) Number and date of contract
c) Data of manufacture
d) Other markings pertaining to the test item

3) Weight, in lbs.
4) Physical dimensions (length, width, height) in inches
5) Type of material

6) Ease of uncrating
7) Method of packing
8) Equipment required for unpacking
9) Adequacy of uncrating instructions
10) Evidence of damage or deterioration
11) Evidence of incompleteness
12) Evidence of wear
13) Evidence of defects

a) Manufacturing
b) Material
c) Workmanship

14) Whether mat bundles had been secured according to the appropriate specifications.

b. Retain all photographs

6.3.1.3 Safety

a. Record whether the test item, its associated tools and equipment are nontoxic and nonhazardous to personnel when used in accordance with instructions from the developer.

6.3.2 Test Conduct

6.3.2.1 Laboratory Tests

6.3.2.1.1 Physical Characteristics -

Record data collected as described in the applicable sections of MTP 10-2-500 and record the following:

a. Cubage of each bundle of mats, in ft^3
b. Weight of each bundle of mats, in pounds
c. Placing dimensions of each bundle of mats, in ft^2
d. Overall dimensions of each bundle of mats, in ft^2
e. Functional performance, when applicable of:

1) Latches
2) Hinges
3) Closures, etc.

f. Alloy
g. Tolerances in side joints, etc.
h. Weight
i. Fit
j. Adhesion of anti-skid additive
k. Panels that dish transversely
l. Use of appropriate coding according to statistical design number, capacity, serial number, lifting points, etc.
m. Existance of shortages

n. Micrometer measurements to the nearest .01 of an inch
o. Results of inspections of:

1) Replacement mats
2) Aircraft tiedowns
3) Ninety degree connectors
4) Starter keylock
5) Typical keylock
6) Arresting gear rubrail
7) Transition mat section
8) Anchorage items
9) Expandable panels
10) Starter and access adapters

6.3.2.1.2 Durability -

a. Record data collected as described in the applicable portions of MTP 10-2-502 including the following:

1) Tensile test
2) Beam test
3) Aging test
4) Extreme temperature test

b. Record the following:

1) Durability of anti-skid coating
2) Waterproofing capabilities before and after tests
3) Resistance to adverse weather conditions, aircraft engine exhaust, and fuels
4) Percentage of expansion/elongation during temperature changes as specified

6.3.2.1.3 Skid-Resistance and Tire-Wear Tests -

Record the following for each direction of pull:

a. Direction of pull
b. Length of pull, in feet
c. Tire pressure, psi
d. Load weight, in pounds
e. Average force required to keep cart moving, in ft-lbs.
f. Comparative tire wear

6.2.3.1.4 Trafficability and Wheel Load Tests

a. Record the following:

1) Single-wheel load weight in pounds
2) Tire pressure, in psi

3) Tire contact area, in in^2
4) Wheel coverage
5) Soil CBR
6) Ability to withstand single wheel loads and tire pressure without significant deformation or damage
7) Condition and performance of waterproof properties
8) Functioning of all mat accessories

a) Functional suitability
b) Tolerances
c) Weight in pounds
d) Fit
e) Aircraft tiedown strength

9) Any material failure

a) Identity
b) Description of failure
c) Location of item at failure
d) CBR of soil under item at failure
e) Number of load coverages sustained by failed item

10) Centerline profile and cross section survey data
11) Deflection and/or mat creep

a) Magnitude of creep
b) Location of creep
c) Resulting buckling, if applicable

b. Retain all photographs

6.3.2.2 Field Tests

6.3.2.2.1 Pre-Test Preparation -

a. Topographical Data -- record the topographical survey and construction data.
b. Soil strength test -

1) Record the following for each soil sample:

a) Sample location
b) Soil CBR

(1) Penetrometer
(2) Truck gauges

c) Soil Water content in grains per in^3
d) Soil density in pounds per ft^3

2) Record the dust proofing capabilities inherent in the mats

and dust palliatives

c. Installation -- record the following:

1) Time to install
2) Effort and difficulties encountered
3) Special tools or supplies needed that were not supplied
4) Adequacy of accompanying directions and specifications
5) Fit and interchangeability of parts
6) Centerline profile and cross section survey data
7) Positions of fixed reference points

6.3.2.2.2 Aircraft Operations -

a. Record the following

1) Centerline profile and cross section survey data
2) Positions of the fixed reference points
3) Aircraft shock and vibration data
4) Profilometer readings
5) Daily flight operation data
6) Conditions of test material
7) Pilot reactions
8) Effects of surface roughness on aircraft, structurally

a) Centerline profile and cross section survey data
b) Magnitude of mat creep, in inches
c) Location of mat creep
d) Buckling, if applicable

b. Retain all photographs

6.3.2.3 Maintenance Evaluation

Record data collected as described in the applicable sections of MTP 10-2-507.

6.3.2.4 Human Factors

Record data collected as described in the applicable sections of MTP 10-2-505.

6.3.2.5 Safety Evaluation

Record the following:

a. Conditions that might present safety hazards
b. Cause of safety hazards
c. Action taken to alleviate hazards

d. Special precautions required for operating and maintaining the test item.

6.3.2.6 Environmental Testing

Record data collected as described in MTP 10-4-001, 10-4-002, and 10-4-003, as applicable.

6.3.2.7 Value Analysis

Record the following:

a. Personnel comments
b. Any features that could be eliminated
c. Cost of test item
d. Cost of comparable existing items

6.4 DATA REDUCTION AND PRESENTATION

Present the test data using charts and graphs as appropriate. Evaluate the test data by determining the extent to which they meet the requirements of the TC's and MS's for the mats.

6.4.1 Coefficients of Friction

The coefficient of kinetic friction of the mat surface shall be determined as follows:

$$\mu = \frac{F}{N}$$

where: μ = coefficient of kinetic friction
F = average force required to pull the load cart across the mat surface
N = the normal force incurred by the load or the weight of the load

NOTE: Tire pressures affect the coefficient of friction. Determine the coefficient of friction for all specified tire pressures.

6.4.2 Deflection and Mat Creep

Compare results of pre-test and post-test measurements of the reference points established in paragraph 6.2.2.1.3 to determine the magnitudes of mat deflection and/or mat creep.

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APPENDIX A

CALIFORNIA BEARING RATIO (CBR) METHOD

A. General

1. Development and Definition

The California Bearing Ratio (or CBR Method) with its numberous variations is probably the most widely used method of designing asphalt pavement structures. This method was developed by the California Division of Highways around 1930 and has since been adopted and modified by numberous states, the U. S. Corps of Engineers, and many countries of the world. The Corps of Engineers adopted this method during the 1940's, and their test procedure is most generally used, with and without certain modifications. In 1961, the American Society for Testing and Materials adopted the method as ASTM Designation D 1883, Bearing Ratio of Laboratory-Compacted Soils. The ASTM procedure differs in only minor respects from the Corps procedure. The Corps method has been followed rather closely in preparing this Chapter.

The CBR is a comparative measure of the shearing resistance of a soil. It is used with empirical curves to design asphalt pavement structures. This test consists of measuring the load required to cause a plunger of standard size to penetrate a soil specimen at a specified rate. The CBR is the load, in pounds per square inch, required to force a piston into the soil a certain depth, expressed as a percentage of the load, in pounds per square inch, required to force the piston the same depth into a standard sample of crushed stone. Usually depths of 0.1 inch or 0.2 inch are used, but depths of 0.3, 0.4, and 0.5 inch may be used if desired. Penetration loads for the crushed stone have been standarized. The resulting bearing value is known as the California Bearing Ratio, which is generally abbreviated to CBR, with the percent omitted.

2. Scope

This test method is intended to provide the relative bearing value, or CBR, of base, subbase, and subgrade materials. Procedures are given for laboratory-compacted speciments of swelling, nonswelling, and granular materials. Moreover, procedures are described for performing in-place field tests and tests upon undisturbed samples obtained from the field.

Tests on laboratory-compacted specimens are performed usually to obtain information which will be used for design purposes. The in-place field test can be used under certain conditions to determine the loadcarrying capacity of material in place in the field. When the in-place field test is performed on materials which may later and during the life of the pavement undergo changes of moisture content, undisturbed samples of the field-compacted materials are tested in the laboratory for conditions of moisture content simulating those expected in the field.

3. Auxiliary Soil Tests

There are certain routine soil tests which should be performed prior to conducting the CBR test. These tests are as follows:

STANDARD TESTS	DESIGNATION	
	AASHO	ASTM
a. Sieve Analysis of Fine and Coarse Aggregate	T 27	C 136
b. Liquid Limit of Soils	T 89*	D 423*
c. Plastic Limit of Soils	T 90*	D 424*
d. Calculating the Plasticity Index	T 91*	D 424*
e. Mechanical Analysis of Soils (only for classification purposes)	T 88	D 422
f. Specific gravity of $+4$ material	T 85	C 127
g. Field density test	T 147	D 1556

*Note: The Corps of Engineers has modified, as follows, the methods of test for liquid limit and plastic limit of soils:

1. The sample shall not be oven-dried, nor subjected to any artificial drying before processing for testing.

2. The sample shall be soaked in water for 24 hours prior to washing.

3. The sample shall be washed through the No. 40 sieve. Material retained on the sieve shall be dried, then dry-sieved through the No. 40 sieve. The portion dry-sieved through the No. 40 sieve shall be combined with the material washed through the sieve. This combination shall be used for the liquid limit and plastic limit tests.

4. The sample shall be set aside and the water decanted or wicked off. No chemicals shall be added to hasten settlement of the fines. The sample shall be dried to approximately the liquid limit with care being taken to prevent caking or lumping during the drying process. The liquid limit test shall be performed from wet of the liquid limit to dry of the liquid limit, using the mechanical method. No dry soil shall ever be added to the sample during performance of either the liquid limit or the plastic test.

5. Water content shall be further reduced by air drying and the plastic limit performed. Drying shall not proceed below the plastic limit. Care shall be taken to prevent caking or lumping during drying.

6. The plastic limit test shall be performed on a ground glass plate.

7. Modifications to the soaking time to the method of hastening settlement of the fines will be made when check tests of the specification material show that the modifications do not affect results.

B. Determination of CBR for Remolded Specimens

1. General

The CBR value for a soil will depend upon its density, molding moisture content, and moisture content after soaking. Since the product of laboratory compaction should closely represent the results of field compaction, the first two of these variables must be carefully controlled during the preparation of laboratory samples for testing. Unless it can be ascertained that the soil being tested will not accumulate moisture and be affected by it in the field after construction, the CBR tests should be performed on soaked samples.

2. Equipment

The equipment and materials required for determining the CBR value of a soil consists of the following items described as follows:

a. Cylindrical Mold-6 in. inside diameter, 7 in. deep provided with a collar extension about 2 in. length. A perforated base plate with perforations not greater than 1/16 in. diameter is required for specimen preparation. A base plate without perforations is employed for compaction control tests.

The base plate and collar should be made to clamp on either end of the mold. For any group of molds, one extra base plate is desirable, since two plates are required when a mold is inverted during specimen preparation.

b. Spacer Disc-metal, 5 15/16 in. diameter x $2\frac{1}{2}$ in. high.

c. Compaction Hammer-sliding weight or sleeve type, 2 in. diameter steel tamping foot, 10lb. weight with an 18 in. fall.

d. Sieves-3/4 inch and a No. 4.

e. Expansion Apparatus-adjustable stem and perforated plate, tripod, and dial micrometer (reading to 0.001 inch) suitable for measuring the expansion of the soil.

f. Weights-one annular and several split 5 lb. weights, 5 7/8 in. outside diameter and 2 1/8 in. inside diameter suitable to apply as surcharge

loads on soil surface during soaking and penetration.

g. Penetration Piston-1.95 inch diameter face (three square inches) and sufficiently long to pass through the surcharge weights and penetrate the soil.

h. Loading Device-laboratory testing machine or screw jacks and frame arrangement which can be used to force the penetration piston (plunger) into the soil specimen at a uniform rate of 0.05 inch per minute.

i. Coarse filter paper, wire screen, and cellophane.

j. Equipment for conducting routine soil tests listed under Article A.3.

k. Miscellaneous Apparatus-mixing bowls, dial micrometers, spatulas, straightedges, trowels, knives, spoons, scales, soaking tank, ovens, moisture content cans or boxes and stop watch.

3. Soil Preparation

a. Air-dry the total sample until it becomes friable under a trowel. Approximately 75 lbs. of material passing the 3/4 inch screen will be required.

b. Break up soil aggregations, being careful to avoid reducing the natural size of the individual particles.

c. Separate the sample into three fractions over the 3/4-inch and No. 4 sieves.

d. Discard all material retained on the 3/4-inch sieve, and replace it with an equal portion of original material passing the 3/4-inch sieve and retained on the No. 4 sieve.

e. Recombine and thoroughly mix the sample.

f. Place prepared soil sample in a moisture proof container.

g. Oven-dry approximately 500 grams of the material just prepared, to determine its moisture content. Moisture content is determined as follows:

$$w = \frac{W_1 - W_2}{W_2} \times 100$$

where w = moisture content in percent based on oven-dry soil weight.

w_1 = weight of wet soil.

w_2 = weight of oven-dry soil.

4. Procedure for Conducting the Compaction Control Test

The compaction control test used by the Corps of Engineers is a modification of the Standard AASHO Designation T99 and essentially corresponds to Method D, Designation T180. Modifications made by the Corps of Engineers are as follows:

a. The mold shall be as specified in Article B2a.

b. The compaction hammer shall be of the sliding weight type. It shall consist of a two-inch diameter steel tamping foot, a 5/8-inch steel rod, a weight with an 11/16-inch hole through the center, and a handle. Construction of the tamping foot and weight shall be such that tamping blows can be applied adjacent to the sides of the mold. The rod shall be attached to the tamping foot with a spring cushion. The maximum allowable weight of the assembled compaction hammer is $17\frac{1}{2}$ pounds.

c. The preparation of the soil shall be as described in Article B.3.

d. No material shall be re-used, and a separate batch shall be used for each compaction test specimen.

e. The desired amount of mixing water for each test specimen shall be added, mixed well, and the material placed in a container with an airtight cover and allowed to cure for 24 hours. The water content should be re-determined if appreciable condensation occurs on the container wall.

f. Clamp the mold and detachable collar extension to the base plate, insert the spacer disc, and place a coarse filter paper on top of the disc.

g. Compact the specimen in five one-inch layers, each layer receiving the required number of blows of the specified tamper or hammer.

h. For cohesive materials, the water content tested shall range from below to above the estimated optimum; for cohesionless materials, the water content shall range from air-dried to as high as practicable.

i. Modifications to the above procedures may be made when check tests on the specified materials show that the modifications do not affect the results.

j. Place the mold assembly on a concrete floor or pedestal during compaction.

k. Compact a sufficient number of test specimens over a range of water contents to definitely establish the optimum water content and the maximum density. If compaction characteristics of the material are fairly well known, four or five specimens compacted at water contents within the range of ± 2% of optimum water content are usually enough to establish the optimum water content and the maximum density.

1) Plot the test results in the form of a moisture-density diagram, and draw a smooth curve through the points.

5. Preparation of Test Specimens

a. Assemble the 6-inch mold, extension collar, and perforated base plate by clamping the mold with fitted extension collar to the base plate.

b. Insert the spacer disc over the base plate, and place a 6-inch diameter coarse filter paper on top of the disc.

c. Compact samples using compacting efforts and molding water content as indicated below. Specimens are usually compacted at several moisture contents and densities to cover the anticipated range that will be experienced in the field. In preparing remolded specimens for the CBR method of design, all subgrades and base courses have been grouped into three classes with respect to behavior during saturation: (a) cohesionless sands and gravels, (b) cohesive soils, and (c) highly swelling soils. The first group usually includes the GW, GP, SW, and SP classifications.* Swelling soils usually comprise the MH, CH, and OH Classifications. Separate procedures for sample preparation are given for each of the groups.

1) Cohesionless sands and gravels. Cohesionless soils usually compact readily under rollers or traffic, and specimens should be prepared at high densities and at a range of water content covering those anticipated in the field and including water contents as high as practicable. Using predetermined and plotted moisture-density relationship, compact samples (using the same procedures as outlined for compaction control test in Article B4) at optimum moisture content, and on the wet and dry side of optimum. Molding moisture content may be obtained by drying a portion of the sample (100 grams for clays and 500 grams for gravelly soils) at the time the specimen is compacted. Soaking may be omitted in subsequent tests on the same material if it does not lower the CBR. Usually the lowest CBR value obtained from this series of specimens is used as the design CBR.

2) Cohesive Soils. Soils in this group are compacted and tested in a manner to develop data that will show their behavior over the entire range of anticipated moisture contents for representative samples. Compaction procedures are similar to those outlined in Article B.4, except that compaction curves are developed for 55, 26, and 12 blows per layer and each specimen is soaked and penetrated to develop a complete family of curves showing the relationship between density, water content, and CBR. To aid in determining the validity of the compaction data, a semilog plot of maximum density versus compaction effort in work per unit volume usually gives a straight-line relationship. The data from a CBR test are plotted, and the resulting family of CBR curves represents the characteristics encompassing a wide range of field conditions. The design CBR should be based on the density and molding-moisture content anticipated in the field.

*Unified Soil Classification System

3) Swelling Soils. The sample preparation procedures for highly swelling soils are the same as previously described for cohesive soils; however, the objectives of the testing program are not exactly the same as for cohesive soils. Tests are performed on soils with expansive characteristics to determine a moisture content and a unit weight which will minimize expansion. The proper moisture content and unit weight are not necessarily the optimum moisture content and unit weight determined by AASHO T180 Method D compaction tests. Generally, the minimum swell and highest soaked CBR will occur at a molding moisture content slightly wetter than optimum. It may be necessary, when testing highly swelling soils, to prepare samples for a wide range of moisture contents in order to establish the relationship between moisture content, density, swell, and CBR for a given soil.

Moisture, density, and CBR data should be plotted just as for cohesive soils. In addition, percent of swell should be plotted versus molding water content for the various compaction efforts in the same way that CBR and density. A comparison of the plots of swell, CBR, and density versus molding water content will permit selection of specification limits for moisture and density. This also will permit the limitation of swell and, at the same time, give the greatest values of CBR and density which might reasonably be obtained. Then, just as for cohesive soils, design CBR and density values would be selected toward the bottom of the ranges in CBR and density, consistent with the specification limits selected.

Where it is desirable to limit swell by the addition of overburden load, tests will have to be conducted to determine the amount of load necessary. These tests can consist of additional specimens, prepared for soaked CBR tests, using various added amounts of surcharge during soaking. The amount of surcharge required to limit swell to a permissible amount then can be used to compute the needed thickness of overburden. The same result may be accomplished with fewer specimens by restricting the swell during soaking and measuring the pressure developed.

d. After each sample has been compacted in the mold, remove the extension ring; strike off excess soil with a straightedge; remove the base plate; and extract the spacer disc.

e. Weigh the mold and compacted soil to determine the density of soil.

f. Place filter paper on the base plate; invert the cylinder so that the bottom during compaction is now on top; re-attach to the base plate; and place filter paper on top of soil in mold.

g. Place the perforated aluminum plate, with adjustable stem attached, on the filter paper.

h. Place surcharge weights on the aluminum plate to produce an intensity of surcharge loading equal to the weight of the base material and pavement within ± 5 pounds, but not less than 10 pounds.

i. Immerse the mold and weights in water to within 1/2 inch of the top of the mold. Place blocks under the mold to allow free access of water to the bottom of the specimen, and put water inside the mold to the same level as water on the outside of the mold.

j. After immersion, measure the height of the stem or spindle above the edge of the mold with the dial micrometer and tripod assembly. This is the initial measurement for swell.

k. Allow the specimen to soak for four days, maintaining constant water level outside and inside the mold.

l. Repeat step j to obtain the final swell measurement. Compute the swell as a percentage of the initial specimen height.

EXAMPLE

Swell Data

Reading after 4 days	0.405 in.
Original reading	0.388 in.
Swell (difference)	0.017 in.

$$\text{Swell (\%)} = \frac{\text{swell}}{\text{ht. of specimen}} \times 100 = \frac{100 \times 0.017}{5} = 0.34\%$$

m. Remove the mold from the water, and pour off free water from inside the mold, being careful not to disturb the soil.

n. Remove the surcharge weights, perforated plate, and filter paper, and allow the specimen to drain for 15 minutes.

o. Weigh the specimen to determine the soil density. The specimen is then ready for the penetration test.

6. Procedure for Penetration Testing

NOTE: This procedure is the same for all types of remolded specimens. Moreover, it is also applicable for undisturbed and field in-place tests after the testing surface has been prepared.

a. Place one 5-pound annular disc surcharge weight on the soil surface.

b. Place the mold in the loading frame or hydraulic press, and adjust its position until the piston is centered on the specimen.

c. Seat the penetration piston with a 10-pound load, and set both the load dial and strain dials to zero. This initial load is required to insure satisfactory seating of the piston and should be considered as the zero load when determining stress-penetration relations.

d. Add penetration surcharge weights to produce an intensity of loading equal to the weight of the base material and pavement (within ± 5 pounds), but not less than 10 pounds. If the sample has been previously soaked, the surcharge should be equal to the soaking surcharge.

e. Apply the load to the piston at a uniform rate of 0.05 inch of penetration per minute.

f. Record the total load readings at 0.025, 0.050, 0.075, 0.100, 0.125, 0.150, 0.175, 0.200, 0.250, and 0.300 inches penetration.

g. Release the load; remove the mold from the loading device; remove the weights; and detach the base plate.

h. For laboratory tests, determine the average moisture content for the entire depth of the sample. For field tests, take a sample of soil from the top inch for moisture content.

i. Remove and discard the remaining soil.

j. From the loads obtained in f, the CBR of the sample is determined, as illustrated in Section E.

C. Tests on Undisturbed Specimens

1. General

Tests on undisturbed samples may be used for design where the natural condition is the controlling factor. They may also be used for correlation of field in-place test results with design moisture. For the latter condition, duplicate samples should be obtained. One should be tested at natural or in-place water content and the other at design water content to

determine the correction to be applied to the results of the in-place tests, i.e., the reduction in CBR that occurs during the soaking should be applied as a correction to the results of the field in-place tests.

2. Equipment

The equipment required for determining the CBR of undisturbed specimens consists of the items listed below:

a. Equipment required for CBR penetration test in the laboratory as previously described.

b. Compaction Molds, CBR: as previously described. To be used for obtaining samples of soft fine-grained soils that will completely fill the mold.

c. Sampling Collar: Edge sharpened for cutting through soil.*

d. Metal Split Jacket Mold: 7-inch diameter and 7 inches high.*

e. Wooden Box: Removable top and bottom.

f. Wax Paper or Paraffin.

g. Miscellaneous Apparatus: Shovel, saw, knives, resin, adhesive tape, heating apparatus, and can for heating paraffin.

3. Obtaining a Sample with CBR Mold

a. Smooth the ground surface, and press the sampling collar, mold, and extension collar into soil with moderate pressure, holding disturbance of the specimen to a minimum.

b. Excavate a trench around the mold, and press the mold down firmly over the soil.

c. Trim soil away from the sampling collar with a knife by cutting downward and outward to avoid cutting into the sample.

d. Excavate the trench deeper and repeat the above procedure until the soil is well into the extension collar. (If stones interfere, pick out carefully and backfill with soil, making note of this in sample log.)

e. Cut off the sample at the bottom of the mold with a knife, shovel, or saw and remove from the hole.

f. Remove the extension collar, and trim the top surface of the soil level with the ends of the mold. Remove the sampling collar, and repeat trimming process. Trimmings, or samples from an adjacent hole, can be used for moisture content determinations.

*These are usually improvised by the laboratory.

g. Protect both ends with paraffin or wooden discs, and tape around the edges and over sides of mold. Wrap in a damp cloth to prevent moisture loss while transporting to the laboratory.

h. The dry unit weight of the sample may be obtained by means of a field density test performed in an adjacent hole.

4. Obtaining Sample with Split Jacket

A split jacket cylinder should be used for soils that cannot be sampled with the CBR mold.

a. Smooth the ground surface. On the surface, mark the outline of the soil chunk to be sampled, excavate a trench around chunk, deepen the excavation, and trim sides of the chunk with a butcher knife. Obtain moisture content samples from the trimmings.

b. Trim the sample to a size slightly smaller than the jacket, and place jacket over sample.

c. Fill the sides and top of the sample with warm paraffin and 10 percent resin.

d. Cut off the bottom of the sample, remove the jacket and sample from the hole, trim sample surfaces, and seal the ends with paraffin and resin for transportation to the laboratory.

e. The dry unit weight of the sample may be obtained by means of a field density test performed in an adjacent hole.

5. Obtaining a Box Sample

This method of sampling is recommended for gravelly soils. An undisturbed sample is obtained with an openended wooden box in a manner similar to that used for obtaining a split jacket sample. The sample is encased on all sides, top and bottom, in a thick layer of paraffin, and then a wooden top and bottom are placed on the box for shipment to the laboratory. Moisture content and dry unit weight may be obtained in an adjacent hole.

6. Preparation of Samples for CBR Testing

a. In the case of compaction mold samples, remove the protective cover from one end of the sample, and trim or fill with sand to produce a surface that is flush with the end of the mold. Then place a wire screen or filter paper over the trimmed end of the sample, and attach the perforated base plate. Invert the mold, remove the protective covering from the other end, and smooth this surface also. Attach the extension collar, and the sample is ready for soaking.

b. For samples in the split jacket, loosen bolts, expand the jacket, and loosen the sample from sides. Extrude the sample so that it extends about one inch beyond the end of the jacket, and then reclamp. Remove exposed paraffin with a knife, and carefully trim the sample down to the rim of the jacket. Again, loosen the bolts, and lower the sample back to the original position. Tighten the bolts, and the sample is now ready for soaking.

c. For box samples, remove the top, and carefully cut away paraffin. Level the surface with sand.

d. The procedure for soaking undisturbed specimens is the same as for laboratory-compacted specimens.

7. Procedure for Penetration Testing

The specimens shall be penetrated as described in Article B.6 and the CBR value calculated as shown in Section E, Calculations.

D. Field In-Place Tests

1. General

The field in-place test is, under certain conditions, a satisfactory test for determining the load-carrying capacity of a material in place in the field. Basically, the penetration phase of this test is the same as described previously. The field in-place test may be used under any one of the following conditions:

a. When the in-place density and water content are such that the degree of saturation (percentage of voids filled with water) is 80 percent or greater.

b. When the material is coarse-grained and cohesionless so that it is not affected by changes in water content.

c. When the material has been in place for several years. In cases such as this, the water content does not actually become constant but appears to fluctuate within rather narrow ranges, and the field in-place test is considered a satisfactory indicator of the load-carrying capacity. The time required for the water content to stabilize cannot be stated definitely, but the minimum time is about three years.

Three in-place CBR tests should be performed at each elevation tested in the base course and at the surface of the subgrade. However, if the results of these three tests do not show reasonable agreement, three additional tests should be made. A reasonable agreement between three tests, where the CBR is less than 10, permits a tolerance of 3; from 10 to 30, a tolerance of 5; and from 30 to 60, a tolerance of 10. Above a CBR of 60, variations in the individual readings are not of particular importance. For example, actual test results of 6, 8, and 9 are reasonable and can be averaged as 8; results of 23, 18, and 20 are reasonable for an average of 20. If the first three tests do not fall within

this tolerance, then the three additional tests are made at the same location, but not the same spot, and the numerical average of the six tests is used as the CBR at that location. Generally, CBR values below about 20 are rounded off to the nearest point; those above 20 rounded off to the nearest 5 points.

2. Equipment

The apparatus for field testing consists of the following:

a. Loading Device: Mechanical screw jack to apply load, truck jacks, and loaded truck to provide resistance for screw jack.

b. Penetration Piston: 1.95-inch diameter (three square inch face area), six-inch length, with internally threaded pipe extensions and connectors.

c. Dial Micrometers and Support.

d. Surcharge Weights: Described in Article B2 f.

e. Calibrated Proving Rings.

f. Steel Plate: 10-inch diameter, 10 pounds in weight with a 2 1/32-inch diameter hole in the center.

g. Small channel beam or other rigid beam at least six feet long for use as a datum plane for measuring penetration.

h. Miscellaneous Equipment: Stop watch, pick, shovel, knives, spoons, moisture content cans, and straightedge.

3. Test Procedure

a. Select a test site with no exposed stones larger than 3/4 inch, level the surface, and remove all loose material.

b. Position the truck over the test site, and jack up so there will be no load on the rear axle.

c. Place the required surcharge weights in the center of the test area, and set the assembled test apparatus in position.

d. Then follow the procedure described in Article B.6. a-g.

e. After completion of the test, obtain soil samples at the point of penetration for in place moisture content determination.

f. Make an in-place density determination at a point about 4 to 6 inches away from the point of penetration.

E. Calculations

1. Stress-Strain Curve

After the test has been completed, the penetration unit load in psi is calculated and the stress-strain curve plotted on cross-section paper. In order to obtain true penetration loads from the test data, the zero point of the curve is adjusted to correct for surface irregularities and the initial concave upward shape of the curve if it is present. If the curve is uniform the CBR value is calculated from the recorded loads. For surface irregularities extend the straight line portion of the curve to the base to obtain a corrected origin, or zero. If the curve has a reverse bend, or concave upward shape, draw a line tangent to the steepest point of the curve, and extend the line to the base to obtain a corrected origin or zero point. Then read the corrected load values for 0.1-inch penetration and 0.2-inch penetration.

2. Calculation of California Bearing Ratio

The CBR value is defined as a ratio comparing the bearing of a material with the bearing of a well-graded crushed stone. The penetration loads for crushed stone are presented in the following table:

Penetration in Inches	Standard Load (lbs)	Standard* Load (PSI)
0.1	3000	1000
0.2	4500	1500
0.3	5700	1900
0.4	6900	2300
0.5	7800	2600

*Plunger cross-section area = 3 square inches.

The corrected load values, obtained as prescribed in Article 8.20, are determined at 0.1-inch and 0.2-inch penetration from which the CBR values are determined by use of the following formula:

$$\text{CBR } (\%) = 100 \frac{x}{y} \qquad x = \frac{aD}{3}$$

where, x = soil resistance or the unit load on the piston, psi (for 0.1 inch of penetration interval)

y = standard unit load, psi.

a = value of one dial division, lbs.

D = actual dial reading

The CBR is determined from the corrected load values at 0.1-and 0.2-inch penetrations by dividing the loads at 0.1 and 0.2 inch by the standard loads of 1000 and 1500 pounds per square inch, respectively. Each ratio is multiplied by 100 to obtain the CBR in percent. The CBR is usually selected at 0.1-inch penetration. If the CBR at 0.2 inch penetration is greater, the test should be rerun. If check tests give similar results, the CBR at 0.2-inch penetration should be used.